AN ANALYSIS OF COOLING TIME IN PLASTIC INJECTION MOULDING WITH INFLUENCE OF INLET TEMPERATURE OF COOLING FLUID

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Abstract—A numerical analysis was carried out to study the effect of the inlet temperature of cooling fluid on the cooling time in plastic injection moulding. Mold data consists of two different steel which designed so as to form the two sides of the plastic part. Water flowing through horizontal cooling channels was usedas cooling fluid for the cooling of theplastic parts.A numerical analysis using a finite volume approach was carried out. The effect of inlet temperature of cooling water on the temperature distribution of the partsand the solidification degree of the parts wereinvestigated. The results indicate that the cooling time in plastic injection mouldingdecreased with the inlet temperature of cooling water.

Keywords—PlasticInjectionMoulding, CoolingChannels, Cooling Time.

I. INTRODUCTION

Plastic injection mouldingis of great importance for engineering applications particularly in the automotive industry. Therefore, there have been several previous investigations on the plastic injection moulding and cooling systems such as; Hassan et al. [1] carried out a 3D study of cooling system effect on the heat transfer during polymer and indicated that, for the same cross-sectional area and coolant flow rate of the cooling channels, the cooling channels having the form rectangular perform the minimum time required to completely solidify the plastic product. Tang et al. [2] worked out about design and thermal analysis of plastic injection moulding and reported that shrinkage is likely to occur in the region near the cooling channels as compared to other regions.Liang and Ness [3] calculated the cooling time in injection moulding and presented a simplified heat transfer model and a new equation for calculating the cooling time.Li [4] explored a feature-based approach to injection mould cooling system design. Hassan et al. [5] carried out a 3D study on the effect of gate location on the cooling of polymer by injection molding and reported that the temperature distribution through the output product is greatly affected by the position of the injection gatelocation. Zhang et al. [6] and Zhou et al. [7] developed a rapid BEM-based method for cooling simulation of injection molding. They reported that this developed approach is a cost-effective method for BEM-based simulation of injection mold cooling.An analysis of thermal contact resistance between polymerand mold in injection molding was conducted by Bendada et al. [8]. They indicated that the thermal contact resistance between polymer and mold is not negligible, not constant with time, and strongly correlated with process conditions. An analytical model was derived and tested for heat transfer in injection moulding systems with coating layers or active heating elements attached to the mould walls by Jansen [9].

In the present study, the effect of the inlet temperature of cooling water on the cooling time in plastic injection mouldingwas examined numerically. The analyses were performed atthe inlet temperature of cooling water of90^0C, 80^0Cand 70^0C for cavityside and 80^0C, 70^0C and 60^0C for core side, respectively.

II. METOD AND APPROACH

The mould was designed based on the actual platen dimension of a plastic injection machine. It was consisted of twostainless steel which were modeled to create a two side of the plastic part. One side of them was called cavity side (fixed side) and the other wascore side (moving side) as shown in Fig. 1. After the injection process of the plastic parts, the parts were remained inthe core side. The cavity plate, core plate and plastic partswas used with dimensions of 310, 310 and 41 mm in width, 210, 210 and 110 mm in height and 56, 75 and 2.2 mm in thickness, respectively. The plastic material which was injected inside the mould at 250°C was selected as PBT (Polybutylene terephthalate). Three design concepts had been considered in the analysis as;

i. 90°C cavity side inlet water temperature; 80°C core side inlet water temperature (Consept 1).
ii. 80°C cavity side inlet water temperature; 70°C core side inlet water temperature (Consept 2).
iii. 70°C cavity side inlet water temperature; 60°C core side inlet water temperature (Consept 3).

The inlet water temperaturesof the cooling channels in the core side werechosencolder to keep the plastic parts on this side when the mold opened.The mold temperature of the cavity side reached constant surface temperature at 84.15, 74.84 and 65.44^{0}Cfor the inlet water temperature of 90^0C, 80^0C and 70^0C respectively, while 79.59, 70.25 and 60.84^{0}C for the core side at the inlet water temperature of 80^0C, 70^0C and 60^0C, respectively.

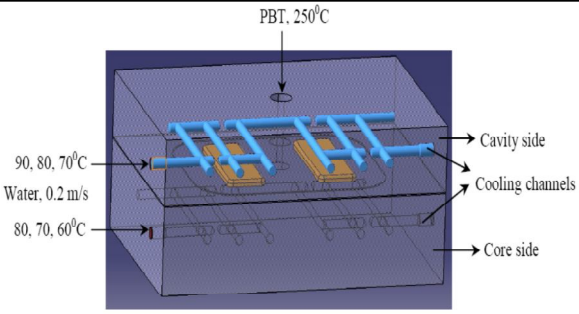


Fig. 1.Configuration of the mold, plastic parts and cooling channels

The geometry of the horizontal cooling channels was defined as circular with a diameter of 10 mm. The homogeneous cooling was generated by the channels in order to remove the plastic parts from the mouldsteadily. The inlet water velocity and pressure was taken as 0.2 m/s and 5 bar respectively, while the environment temperature was 25^0C.

Design and thermal analyses of mould was carried out using FloEFDsoftware, which worked with CAD geometry, Cartesian meshing method and steady state and transient solution, in order to remove the parts from the mould in the shortest possible time without any warpage and deformation.The mesh model included 27728 fluid cells, 38502 solid cells and 29120 partial cells.

The injection of the PBT into the mold cavity, the solidification of the PBT during the cooling process and the flow of the cooling water must take into considerations for the mathematical model. The plastic material and cooling water were considered non-compressible fluids and the physical and thermal properties of the plastic, mold and cooling water werekept constant during the numerical simulation.The mold (steel stainless 321), plastic parts (polybutylene terephthalate) and cooling fluid (water) hada density of 8100, 1300 and 1000 kg/m^3, specific heat of 510, 2000 and 4185 J/kgK and thermal conductivity of 15.1, 0.2 and 0.6 W/mK, respectively.

The software solves the Navier-Stokes equations, which are formulations of mass, momentum and energy conservation laws for fluid flows. The mass and momentum governing equations can be written as follows:

$$\frac{\partial u_i}{\partial x_i} = 0 \qquad (1)$$

$$\rho \frac{\partial u_i u_j}{x_j} = -\frac{\partial P}{\partial x_i} + \mu \frac{\partial}{\partial x_j}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) + \rho \frac{\partial}{\partial x_j}\left(-\overline{u_i' u'}_j\right) \qquad (2)$$

The software allows predicting simultaneous heat transfer in solid and fluid media with energy exchange between them. Heat transfer in fluids is described by the energy conservation equation as:

$$\rho C_p \frac{\partial u_i T}{x_i} = \frac{\partial}{\partial x_i}\left(\lambda \frac{\partial T}{\partial x_i} - \rho \overline{u_i' T'}\right) \qquad (3)$$

The 3D transient heat conduction equation with constant internal heat generation iswritten as:

$$\rho C_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right) + g \qquad (4)$$

where g is heat generated rate. The numerical solution of the mathematical model is computed by finite volume method and the heat conduction equations are solved by an explicit scheme.

The heat radiation leaving a radiative surface is defined as:

$$q_T = \varepsilon \sigma T^4 + \rho_T q_{T,i} \qquad (5)$$

for thermal radiation, where: ε is the surface emissivity, σ is the Stefan-Boltzmann constant, T is the temperature of the surface, $q_{T,i}$is the incident thermal radiation arriving at this surface, $\rho_T$is the surface reflectivity for thermal radiation.

III. RESULTS AND DISCUSSION

The cycle time is very important in the plastic injection molding process due to the cost and efficiency of machines. The most effective parameter in the cycle time is the cooling of the part as shown in Fig. 2.To study the effect of the inlet water temperature on the cooling time, a numerical analysis is carried out in the present study.

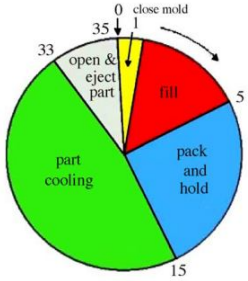


Fig. 2.Cycle time in the injection moulding [10]

The variation of the cooling time with the surface temperature of the solid plastic parts at different inlet water temperatures were shown in Fig. 3. The temperature was taken in the middle of the upper surface of the cavity side of the parts. The cooling time wastakenwhenthe surface temperatures of solid plastic parts reached 90^0C because the parts remove from the mouldbest at this temperature.The cooling times were obtained as69, 45 and 39 seconds atthe inlet water temperature of 90-80^{0}C (cavity side- core side), 80-70^{0}C and 70-60^{0}C respectively.These results indicated that the cooling time decreased with the inlet water temperature because of the augmentation of heat transfer, and so the cooling process was improved. On the other hand, the flow of material part may be decelerated and mouldmay not be filled completely due to the fast cooling of plastic parts. In this case, the usage of high injection or holding pressure to fill the parts loads high stress on the parts and it causes warpage and deformation on the parts.The minimum cooling time obtained at the inlet water temperature of 70-60^{0}C, butthe stress and deformation analysis must be performed before choosing the best cooling time.

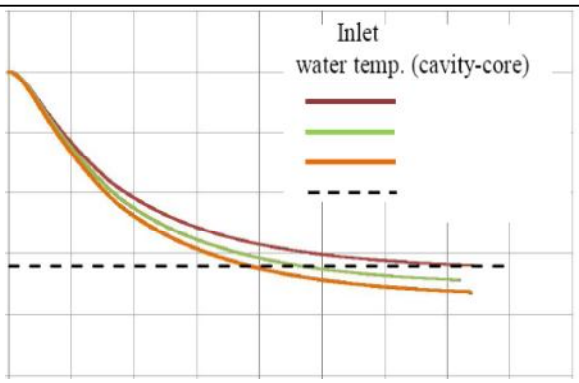


Fig.3. The variation of the cooling time with solid plastic part temperature at different inlet water temperatures

The temperature distributions of upper surfaceof the cavity side of the solid plastic partswhich were obtained at the end of cooling time were also given in Fig. 4 and 5 at the water inlet temperature of 90°C-80°C (cavity-core) and 70°C-60°C (cavity-core), respectively. The inlet water temperatures of the cooling channels in the core side were chosen smaller than the cavity side to remain the parts in core side after the mould opening process. The plastic partsheld on the cooler side of the mould because of the plastic part shrinkage.The results showed that the temperatures of the solid plastic parts reached 90 ± 0.52^0C in the middle of the upper surface at the cavity side for all values of the inlet water temperature.The surface temperatures decreased up to nearly 3^0Ctowards the edge areas of the parts as shown in Fig. 4 and 5 because of the outward cooling of the plastic parts. In order to remove the parts from the mold without warpage and deformation it is required to be cooled uniformly.These temperature differences were within the tolerance limits and the temperature distributions on these parts could be considered relatively homogeneous. The bottom surface temperatures of the cavity side of the partswerelower than those of upper surfacenearly 1^0C.The least cooling time obtained at the minimum inlet temperature of the water while temperature distributions weresimilarfor all inlet water temperatures. But the fast cooling might causes some warpage and load some stress. To obtain better result about the parts deformation, the warpage analysis must be performed.

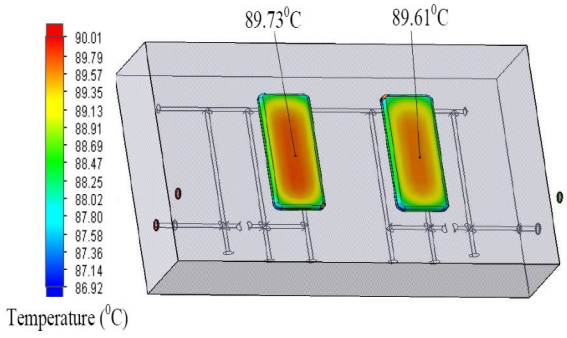


Fig. 4. Temperature distribution of the solid plastic parts at the water inlet temperature of 90°C cavity and80°C core side

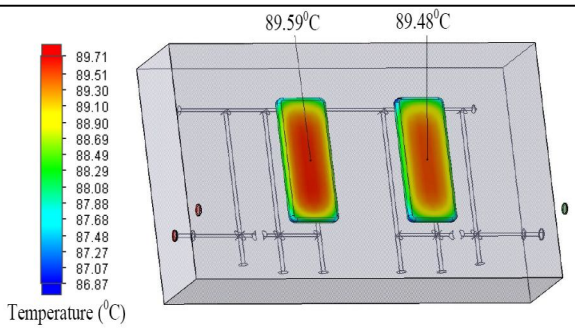


Fig.5. Temperature distribution of the solid plastic parts at the water inlet temperature of 70°C cavity and60°C core side

CONCLUSION

The effects of the inlet temperature of cooling water on the cooling time in plastic injection moulding had been numerically studied.The results of the analysis showed that the cooling time could be shortened by reducing the input water temperature. The minimum cooling time obtained at the inlet water temperature of 70-60^{0}C as 39s and so the solid plastic partscould be removed from the mould after 39 s, but the stress and deformation analysis must be performed before choosing the best cooling time. The results also indicated that the upper surface temperatures decreased up to nearly 3^0C towards the edge areas of the parts. Theupper surface temperatures of the cavity side of the parts werebigger than those of bottom surface nearly 1^0C.

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